The association between childhood ADHD symptoms and adult executive functioning measured with the Rey-Osterrieth Complex Figure in a perinatal risk cohort

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Summary

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Objectives:

This study examines the association between childhood attention deficit hyperactivity disorder (ADHD) symptoms with executive functions (EF) in adulthood by using Boston Qualitative Scoring System (BQSS) analysis of the Rey-Osterrieth Complex Figure (ROCF). In addition, correlations between the BQSS EF scores and self-reported EF difficulties on the Behaviour Rating Inventory of Executive Function- Adult version (BRIEF-A) are explored. ADHD is a developmental disorder diagnostically defined by symptoms of inattention and hyperactivity/impulsivity, in addition to which it has a component related to EF. The symptoms can persist into adulthood and they can affect daily functioning even if the full diagnostic criteria are no longer met.

Methods:

This study is part of a larger longitudinal cohort study of children with perinatal risk factors and their healthy peers. The children have been studied at multiple points during their lives since their birth. Those participants with sufficient information on their childhood ADHD symptoms, and a completed ROCF from the 40-year neuropsychological assessment (n=445) were chosen for this study. The perinatal risk group (n=376) was divided into three groups according to their childhood ADHD symptoms: no symptoms, a medium level of symptoms, and a high level of symptoms. The controls (n=69) had no reported history of ADHD. The association between symptom group and BQSS sub-scales was examined using logistic regression.

Results:

The following ROCF attributes predicted ADHD symptom group membership: Fragmented drawing style in the copying phase, a horizontally expanded reproduction with more perseveration in immediate recall, and a less neat reproduction in both immediate and delayed recall. The differences, barring immediate perseveration, became nonsignificant when gender, level of education and general intelligence (FSIQ) were considered. The correlations between BQSS and BRIEF-A scores were modest, and mostly statistically nonsignificant.

Conclusions:

Based on the findings, those with childhood ADHD symptoms in addition to perinatal risk factors show a slight tendency for less organized and precise performance in the ROCF, albeit one masked by variables such as education and IQ. In line with earlier literature, the correlations between performance-based EF tests and self-reports were mostly slim.

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Rey-Osterreith Complex Figure, Boston Qualitative Scoring System, ADHD, executive functioning, perinatal risk

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Tiivistelmä/Referat – Abstract

Tavoitteet:
Tutkimuksessa tarkastellaan lapsuusajan aktiivisuus ja ylivilkkausoireiden yhteyttä toiminnanohjaukseen aikuisuudessa käyttäen Reyn kuviota arvioituna Bostonin laadullisella pisteytysjärjestelmällä (BQSS). Tämän lisäksi tutkitaan korrelaatioita BQSS-toiminnanohjausskaalojen ja BRIEF-A -kyselyssä itsearvioitujen toiminnanohjauksen vaikeuksien välillä. ADHD on kehityksellinen häiriö, jonka diagnostinen määrittely perustuu tarkkaamattomuuden ja ylivilkkaus/impulsiivisuuden oireisiin. Tämän lisäksi ADHD:seen voi liittyä toiminnanohjauksen oireita. Oireet voivat jatkua aikuisuuteen ja vaikuttaa päivittäiseen toimintakykyyn vaikkei diagnostiset kriteerit enää toteutuisikaan.

Menetelmät:
Tämä tutkimus on osa laajempaa syntymäriskivauvojen ja terveiden verrokkien pitkittäiskohorttitutkimusta. Kohortin jäseniä on kutsuttu seurantaan useita kertoja heidän syntymästään lähtien. Tähän tutkimukseen valittiin osallistujat, joiden lapsuuden ADHD-oireista on riittävästi tietoa, ja jotka tekivät Reyn kuvion kokonaan osana 40-vuotisvaiheen neuropsykologista arviota (n=445). Syntymäriskiryhmä (n=376) jaettiin kolmeen ADHD-oireryhmään: ei oireita (NoADHD), jonkin verran oireita (MeADHD) ja paljon oireita (HiADHD) lapsuusaikana. Verrokeilla (n=69) ei ollut tiedettävästi ADHD-historiaa. Oireryhmän ja BQSS-alaskaalojen yhteyttä tarkasteltiin logistisella regressioanalyysilla.

Tulokset:
Seuraavat Reyn kuvion piirteet ennustivat ADHD-oireryhmään kuulumista: pirstaloitunut piirrostyyli kopiointitehtävässä, sivusuunnassa venynyt ja juuttuvuutta ilmentävä kuva välittömässä mieleenpalautuksessa, ja vähemmän huolellinen piirtojälki välittömässä ja viivästetyssä mieleenpalautuksessa. Lukuun ottamatta välittömän palautuksen juuttuvuutta, nämä ennustajat muuttuivat tilastollisesti ei-merkitseviksi, kun sukupuoli, koulutustaso ja yleinen älykkyys (FSIQ) otettiin huomioon. BQSS-tulosten ja BRIEF-A -arvioiden väliset korrelaatiot olivat vaatimattomia, pääosin ei-merkitseviä.

Johtopäätökset:
Tulosten perusteella vaikuttaa, että lapsuuden ADHD-oireilu voi näkyä lievänä taipumuksena epäjärjestelmällisempään ja huolimattomampaan työskentelytapaan Reyn kuviota piirtäessä, joskin muut muuttujat, kuten koulutus ja älykkyystaso, peittävät yhteyttä. Aiempaan kirjallisuuteen sopien toiminnallisen toiminnanohjauksen testin ja itsearvion korrelaatiot olivat pääosin vähäisiä.

Avainsanat – Nyckelord – Keywords
Reyn kuvio, Bostonin laadullinen pisteytysjärjestelmä, ADHD, toiminnanohjaus, syntymäriski

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Preface

The Perinatal Adverse events and Special Trends in Cognitive Trajectory (PLASTICITY) cohort study project was started by Katarina Michelsson, MD, PhD, and her group in the early 1970's with the aim of researching the effects of perinatal risk factors on later development and cognition. The leadership of the project has since been taken over by Professor Laura Hokkanen. The participants, most of whom have been part of the project since birth, had completed the 40-year assessment phase when I had the chance to join the project to write my master's thesis.

I am grateful for the extraordinary opportunity to participate in this project and gain insight into the study of executive functions and adult ADHD. I wish to thank my instructors, Maarit Virta, PhD, and Professor Laura Hokkanen, for their invaluable guidance and feedback throughout the writing process. I would also like to thank Nella Schiavone, MA, for sharing her work on ADHD symptom evaluation, Lea Enholm, MA, for a fruitful partnership in scoring data, Jari Lipsanen, MA, for his insight in psychometrics, as well as Raakel Hokkanen for language consultation. Finally, I would like to extend my special thanks to the entirety of our master's thesis seminar group, for their support, patience, and helpful comments.

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1. Introduction

Executive functions (EF) have come to refer to a variety of higher cognitive processes related to e.g. self-regulation, goal-oriented behavior, response inhibition, and problem solving. Attention deficit hyperactivity disorder (ADHD) is a developmental disorder diagnostically defined by its symptoms of inattention and hyperactivity/impulsivity (DSM-5: American Psychiatric Association, 2013). In addition to the traditional symptoms associated with it, ADHD has also been found to have a component related to impaired executive functions both in children and adults (e.g. Boonstra, Oosterlaan, Sergeant & Buitelaar, 2005; Holmes et al., 2010; Løvstad et al, 2016). ADHD shows continuity into adulthood (e.g. Kessler et al., 2010; Ebejer et al., 2012) but studies on the persistence of the disorder have produced rather varied results, possibly due to how remission has been defined. Focus on the fulfillment of diagnostic criteria seems to yield higher remission rates compared to when individual symptoms are considered (e.g. Biederman, Petty, Clarke, Lomedico, & Faraone, 2011).

The Rey-Osterrieth Complex Figure (ROCF) was originally developed for assessing visual abilities in patients with traumatic brain injuries but has since been used for the research and clinical assessment of a various cognitive processes, including EF (Shin, Park, Park, Seol, & Kwon, 2006). The task is to draw a detailed geometric figure following a model picture, and then from memory. The Boston Qualitative Scoring System (BQSS) offers a range of quantitative and qualitative sub-scales for assessing ROCF reproductions – among those are scales related to EF. In contrast to many quantitative scoring methods, BQSS considers aspects such as drawing strategy, repetition of elements, as well as fragmentation and distortion of the image, which can serve to deepen the researcher's or clinician's understanding of how a person approaches the drawing task.

The participants of the present study (n=445) are part of the study cohort of the Perinatal Adverse events and Special Trends in Cognitive Trajectory (PLASTICITY) project, most of whom have been participating in the project since birth. This offers an exceptional chance to study the temporal trajectory of ADHD-related symptoms from childhood to adulthood. Thus, the aim of this study is to examine the association between childhood ADHD symptoms and adult executive functioning in a perinatal risk cohort and compare the risk group's performance to unaffected controls. Instead of a strictly diagnosis-focused approach, childhood ADHD is explored through its different symptoms, with sub-diagnostic presentations also taken into account, to more comprehensively capture the varying ways ADHD symptoms can affect a person's functioning.

1.1 Executive functions

1.1.1 Defining executive functions

A variety of definitions for executive functions have been suggested after the emergence of the concept, yet as of now, a clear consensus on what they entail has not been reached. In literature, executive functions is often used as a hypernym for several higher cognitive processes, such as working memory, inhibition, and self-regulation (Goldstein, Naglieri, Princiotta & Otero, 2014). Executive functions are commonly described to have a role in purposeful, goal-oriented behavior or in exerting top-down control over other cognitive domains, e.g. memory and language processes.

A notable early theory put forward by Stuss and Benson (1986, pp. 244-246) describes executive functions as the means by which successful, directed, and efficient information processing in new situations is possible. The model includes anticipation, goal selection, pre-planning, and monitoring as the components of executive functioning which act on other non-executive processes via drive and sequencing. Finally, Stuss and Benson (1986, pp. 246-247) suggest self-awareness as the highest level of what they named frontal lobe functions, overseeing the other processes. This model implies a hierarchical structure of cognitive processing with executive functions at the highest level of functioning, a notion that endures in literature on executive functions to this day.

As the discourse on the definitive nature of executive functions is still ongoing, there is debate over whether they represent a singular entity or as a variety of independent processes. A notable influence in favor of a single unifying construct is found in the study of working memory. In their well-known model, Baddeley and Hitch introduce the concept of a central executive, the role of which is to combine and manipulate information from two sensory slave systems, the phonological loop and the visuospatial sketchpad (Baddeley, 1992). A number of models of executive functions incorporate a mechanism similar to the central executive, e.g. the supervisory attention system suggested by Norman and Shallice (1986) which exerts control on information processing in novel or complicated situations where the so-called automatic response is insufficient.

Other models of executive functions question the existence of a singular central executive or forego the concept entirely. For example, Stuss (2011) posits that, instead of a central executive, there are several discrete domain-general processes with anatomical/functional associations to frontal regions of the human brain. The processes named – energization for dorsomedial, task setting for left dorsolateral, and monitoring for right dorsolateral frontal areas – are rooted in findings from lesion patient groups. Stuss (2011) goes on to suggest two additional frontal functions, behavioral/emotional self-regulation and metacognition/integration, with ties to ventromedial cortex and the polar regions of the frontal lobes respectively. He combines monitoring and task setting under the term executive functions. Thus, in this model, executive functions represent one category among several processes with ties to the frontal lobes, rather than an encompassing central executive or a frontal system.

Finally, there is a plausible argument to be made for executive functions as a family of processes that are distinct from each other while still overlapping with or having connections to one another. Miyake et al (2000) argue in favor of this "diversity and unity" of executive functions based on their findings from factor analyses comparing different measures of executive functions. The model they arrived at consists of three processes that represent discrete executive functions while maintaining some commonality: 1) mental set shifting, which is the ability to move attention between tasks, 2) information updating, the ability to monitor surroundings and add or delete information in the working memory as needed, and 3) the inhibition of prepotent responses to distractors. Miyake et al (2000) go on to hypothesize on the nature of the commonality, proposing working memory or inhibition as the component that works in unison with all of the functions to a degree. In their update to the unity/diversity model, Miyake and Friedman (2012) have indeed foregone the separate inhibition factor, as it was found to have no unique variance after the commonality of EFs, named the common EF, had been taken into account. They describe this common EF factor as the ability to persist in goal-oriented behavior and to use goal-relevant information to guide lower level processing.

1.1.2 Executive functions and the brain

While the term executive functions does not appear in the literature until the latter half of the 20th century, the study of the frontal lobes of the brain dates back to over one hundred years ago. The early findings were largely based on animal studies and, importantly, case reports and studies of patients who had suffered damage to the frontal lobes. Such patients were described as having deficiencies in initiating behavior, purposeful action, and self-evaluation, in addition to exhibiting altered or labile emotions, notable perseveration and significantly tapered interests (Luria, 1966). Many of these behaviors would be attributed to problems in executive functioning in later literature. Following the early studies, significant emphasis was placed on the role of the prefrontal cortex (PFC) in executive functions. However, there is mounting evidence that these processes are not confined within the PFC and that other areas, notably the basal ganglia and thalamus, participate in their execution as well (Andrés, 2003; Krause et al, 2012). Thus, it is more fitting to examine the connecting networks between different brain areas when studying executive functioning, rather than focusing on singular locales.

The PFC can be divided into functional areas, each with looping connections to sub-cortical areas – the ones relevant in the context of executive functioning being the three circuits comprised of different parts of the PFC, striatum, globus pallidus and substantia nigra, and thalamus (Tekin & Cummings, 2002). The dorsolateral prefrontal loop is most directly implicated in so-called cold executive functions, namely the processes of problem-solving and planning; dysfunction of this circuit typically manifests as concrete and perseverative behavior, distractibility, and impairment in reasoning and mental flexibility (Tekin & Cummings, 2002). The orbitofrontal circuit is important to response inhibition and appropriate reacting to social cues and emotional stimuli (Szatkowska, Szymanska, Bojarski, & Grabowska, 2007; Tekin & Cummings, 2002). Dysfunction in this circuit may lead to disinhibited, impulsive, and socially inappropriate behavior, as well as deficiencies in judgement of reward and punishment (Berlin, Rolls, & Kischka, 2004). Finally, the anterior cingulate circuit is central to motivated behavior, with dysfunction manifesting as pronounced apathy (Tekin & Cummings, 2002). The ventromedial prefrontal area anterior to it has been tied to similar processes; the dysfunction of this area can lead to apathy via impaired ability to anticipate rewards (Hovegreen, Hauner, Chau, Krueger, & Grafman, 2016), as well as difficulty in analyzing the motivational aspects of behavior (Stuss, 2011).

The current literature on executive functions is shifting towards examining functional brain networks; information on different network mechanisms can be acquired by studying their stable and task-specific spatial connections in the brain, their temporal dynamics with each other as well as the directionality of the activation (Mill, Ito & Cole, 2017). Based on functional brain imaging studies, a functional system is comprised of brain regions that activate in unison during a certain task (Power et al, 2011). Further, areas that are more strongly connected to each other than the rest of the network can be referred to as network modules (Braun et al, 2015) which contain functional nodes. One study method gaining attention in functional connectivity research is the resting state functional connectivity MRI where the subject's blood oxygen level dependent signals (BOLD) are observed during task-free relaxation (Power et al, 2011). Reineberg and Banich (2016) compared the resting state BOLD activity to the active state where tasks typically connected to the EFs suggested in Miyake et al's model (2000, updated in Miyake & Friedman, 2012) were presented to the subjects. They found that that in addition to the frontoparietal network, nodes from e.g. the temporal lobe and sensorimotor regions showed connectivity during the EF tasks, and that those subjects who showed greater co-activation during rest performed better on the tasks. Further, they found that common EF, switching-specific EF, and updating-specific EF tasks co-activated distinct set of nodes whose connectivity influenced individual differences in those EFs. Braun et al (2015) explored individual differences in EF by examining functional module reconfiguration during working memory and EF tasks. They found that flexibility of the frontal network, that is, the ability to dynamically switch between network module configurations, was associated with enhanced performance in such tasks.

1.1.3 Assessing executive functions

Executive functions can be assessed with various performance-based tests, as well as with self-report and informant-report rating scales. Some well-known performance-based EF assessment methods include the Trail Making Test (Lezak, 2004), the Stroop Task (Stroop, 1935), the Wisconsin Card Sorting Test (WCST, Grant & Berg, 1948), verbal fluency tasks, and the tower tasks, such as the Tower of London test (Shallice, 1982). In addition, there is a variety of methods for wider assessment of executive functioning, such as the Behavioural Assessment of the Dysexecutive Syndrome (BADS, Wilson, Alderman, Burgess, Emslie & Evans, 1996) and the Delis-Kaplan Executive Function System (D-KEFS, Delis, Kaplan, & Kramer, 2001). Some examples of EF rating scales include the child and adult versions of the Behaviour Rating Inventory of Executive Function (BRIEF, Gioia, Isquith, Guy, & Kenworty, 2000; BRIEF-A, Roth, Isquith, & Gioia, 2005) and Barkley Deficits in Executive Functioning Scale (BDEFS for Adults, Barkley, 2011). Especially in clinical contexts, interviews and general observation form an important part of the assessment of executive functioning as well.

An important consideration in the assessment of executive functions has to do with a phenomenon Miyake et al (2000) refer to as the task impurity problem. It is the tendency of many assessment methods of executive functioning to inadvertently measure other interrelated skills and cognitive processes in addition to the intended executive function. These can include, for example, language abilities, visual perception, and intelligence. This issue emphasizes the nature of executive functions as a group of intertwined processes that interact with other related functions, both on a neural level, as discussed above, and on a functional level. With regards to subjective rating scales, differing response styles, the individuals' insight to symptoms, memory issues, as well as differences in attitudes and cultural context may affect the applicability of the results.

Another issue has to do with the ecological validity of the performance-based assessment measures of executive functioning, that is, how well those findings capture a person's daily functioning. Indeed, in their examination of 20 studies comparing performance-based and self/informant-report measures of executive functioning in clinical and non-clinical samples, Toplak, West, and Stanovich (2013) found the correlations between the two method types to be rather modest, with a median correlation of 0.19. Based on the findings, they argue that the performance-based measures and ratings assess different levels of cognitive functioning – the former cognitive efficiency, and the latter successful goal-attainment. In comparison to the natural everyday environment, a professional assessment is carried out in an "optimal" controlled environment where the examiner provides clear instructions and arranges a formal situation where the participant has little control over the events. Lezak (2004) posits that this might lead to a positive bias in the results, since the test environment itself might temporarily alleviate the difficulties.

1.1.4 The Behaviour Rating Inventory of Executive Function

The BRIEF, and its adult version BRIEF-A, is a questionnaire that focuses on different aspects of everyday executive functioning. In the self-report form of the BRIEF-A, the participant answers a series of statements based on his or her experience during the past month. An informant, such as a family member or a spouse, can also fill the form based on his or her observations. The BRIEF has a four-level hierarchical structure. Based on individual items, nine clinical scales are formed: Inhibit, Shift, Emotional Control, Self-monitor, Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials (see Roth, Gioia, & Isquith, 2005 for descriptions). Furthermore, the clinical scales form two indexes: the Behavioral Regulation Index (BRI) and the Metacognition Index (MI). The summary score of these is called the Global Executive Composite (GEC). In addition, the assessment method contains validity scales for answer negativity, inconsistency, and infrequency.

While the BRIEF is suitable for assessing EF in people with varying conditions such as learning disabilities, autism spectrum disorders, traumatic brain injuries, and depression (Roth, Isquith & Gioia, 2005), its use in the evaluation of EF deficits in ADHD is of particular interest to the current study. Both the BRI and the MI have been found to correlate with other teacher and parent reports of daily attention and socio-emotional problems experienced by children referred to a pediatric outpatient clinic for evaluation of attention, learning, or behavioral issues (McAuley, Chen, Goos, Schachar & Crosbie, 2010). Parents and teachers rated children diagnosed with ADHD as significantly more impaired than their typically developed peers on the Inhibit, Working Memory, Shift, and Plan/Organize scales (Davidson, Cherry & Corkum, 2016). Further, McCandless & O'Laughlin (2007) found that the parent and teacher reports on the MI, especially the Working Memory scale, differentiate between children with ADHD and those without it. The BRI, and the Inhibit scale in particular, also differentiate between the combined and inattentive subtypes of ADHD, with children with the combined subtype exhibiting the most dysfunction in these scales, followed by those with the inattentive subtype (McCandless & O'Laughlin 2007).

Adults with ADHD reported significantly more executive dysfunction than the healthy controls in BRIEF-A (Løvstad et al, 2016); the ADHD group scored higher than the controls in both MI and BRI as well as the GEC. All indexes in the ADHD were above the US clinical cutoff t-score (t=65). In their confirmatory factor analysis, Roth, Lance, Isquith, Fischer, and Giancola (2013) arrived at a three-factor model for BRIEF-A where the MI remains as is while the BRI is split into the Behavior Regulation factor (Inhibit and Self-monitor scales) and the Emotional Regulation factor (Emotional Control and Shift). Adults with ADHD reported greater dysfunction on the MI and Behavior Regulation factors, but not the Emotional Regulation factor (Roth et al, 2013).

In line with the findings on the rather modest association between EF ratings and performance-based EF tasks by Toplak, West, and Stanowich (2013) discussed earlier, BRIEF reports seem to generally exhibit weak or no correlation with performance-based measures of EF in children (Davidson, Cherry & Corkum, 2016; McAuley et al, 2010) and adults (Løvstad et al, 2016). However, at least one study with treatment-naïve adults with ADHD did find that omission errors in a Go-NoGo paradigm predicted self-reported problems in BRIEF-A Organization of Materials, and that commission errors predicted similar informant reports (Grane, Endestad, Pinto & Solbakk, 2014).

Once again, this phenomenon could be explained with a rating method such as the BRIEF and performance-based EF tasks measuring different aspects of executive functioning, e.g. goal-oriented strategies and cognitive ability respectively (Toplak, West & Stanowich, 2013). McAuley et al (2010) hypothesize that the performance-based tasks could capture the underlying executive functions while the BRIEF reflects the everyday application of them.

1.2 Attention Deficit Hyperactivity Disorder

1.2.1 Diagnosis and symptoms

ADHD is a neurodevelopmental disorder which is defined as “a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development” (DSM-5: APA, 2013). The disorder can be divided into three types according to the symptoms: the predominantly inattentive presentation, the predominantly hyperactive/impulsive presentation, and the combined presentation where the criteria for both previous types are met. According to the DSM-5 diagnostic criteria for ADHD, several symptoms must be present before the age of 12. They should manifest in more than one environment, and negatively influence the person’s social, academic, or occupational functioning.

The symptoms of ADHD include, among others, restlessness, impatience, distractibility, disorganized and impulsive behavior, and emotional volatility (Kooij et al., 2010). The presence and severity of the symptoms vary depending on the task and the level of motivation; the person may even appear hyper focused when working on an objective of great interest (Bush, 2010). Adults with ADHD can have difficulty in various executive function tasks, especially in those pertaining to response inhibition and working memory; the everyday problems reported by adults with ADHD include difficulties in organization, problem solving, time management, staying motivated and concentrated, and self-discipline (Barkley & Murphy, 2011).

1.2.2 Heritability and early risk factors

ADHD is a developmental disorder with both hereditary and environmental components. Based on twin and adoption studies, the heritability of ADHD is estimated to be 0.7 – 0.9 in children and adolescents (Biederman, 2005; Langner, Garbe, Banaschewski & Mikolajzyk, 2013; Larsson, Chang, D'Onofrio & Lichtenstein, 2014) and 0.3 – 0.5 in adults (Boomsma et al, 2010; Larsson et al, 2013), although at least one study has reported adult heritability as high as 0.72 (Larsson, Chang, D'Onofrio & Lichtenstein, 2014). Environmental risk factors linked to ADHD include maternal smoking, alcohol and drug use during pregnancy, maternal stress in pregnancy, induced labor, early psychological adversity (e.g. poverty and maltreatment), and exposure to some toxins such as organic pollutants and lead (Biederman, 2005; Trapar, Cooper, Jefferies & Stergiakouli, 2012; Silva, Colvin, Hagermann, & Bower, 2014). In addition to these, various perinatal risk factors can elevate the risk of ADHD. The term perinatal risk factor is used to describe a host of events and conditions occurring during the weeks leading to birth, at birth, or the weeks following it, which can adversely affect the health and later development of the child. Perinatal risk factors that have been found to affect later cognitive functioning include, among others, preterm birth, low birth weight, hyperbilirubinemia, maternal diabetes, and neonatal encephalopathy.

The Apgar score system is a widely used method to assess the neonate after birth; the heart rate, respiration, reflex irritability, muscle tone, and color of the infant is examined and each given 0 to 2 points, where 0 signifies a lack of reaction or a concerning condition and 2 a typical or favorable state (Apgar, 1953). Low Apgar scores at one and five minutes have been linked to a variety of adverse neurological sequelae, including cerebral palsy and intellectual disability (Leinonen et al, 2018). Furthermore, there is evidence for association between low Apgar scores (<7) at five minutes and an elevated risk of later ADHD (Gustafsson & Källén, 2011; Halmøy, Klungsøyr, Skjærven, & Haavik, 2012). However, another study found no such link between 5-minute Apgar scores and ADHD (Silva, Colvin, Hagermann, & Bower, 2014).

The definition of a preterm birth varies depending on the source. According to the Finnish Current Care Guidelines (2018), a child who is born before the 37th gestational week can be classified as preterm. Preterm birth has been linked to both global deficiencies in executive function tasks (e.g. Anderson & Doyle, 2004) and to difficulties in specific executive function tasks such as verbal fluency (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever & Oosterlaan, 2009; Aarnoudse-Moens et al, 2012), attention (Marlow, Hennessy, Bracewell & Wolke, 2007; Aarnouse-Moens et al, 2009; Burnett et al, 2015), planning and working memory (Aarnouse-Moens et al, 2009; Aarnoudse-Moens et al, 2012), response inhibition (Aarnoudse-Moens et al, 2012; Nosarti et al, 2007), and mental flexibility (Nosarti et al, 2007; Burnett et al, 2015). Similarly, there is evidence for an association between preterm birth and ADHD (Gustafsson & Källén, 2011; Halmøy, Klungsøyr, Skjærven, & Haavik, 2012).

As with preterm birth, the strict definition of low birth weight varies somewhat between studies; an infant weighing less than 2500 grams can be classified as having low birth weight (Anderson & Doyle, 2004). The low birth weight of a child is often connected to preterm birth; in such cases, a low birth weight neonate can be classified as appropriate for gestational age. A child whose weight is significantly less than the age appropriate norm (e.g. -2 SD, Pyhälä et al, 2011) is, in turn, classified small for gestational age. There is evidence of a connection between low birth weight and impaired executive functions (Harvey, O'Callaghan & Mohay, 1999; Anderson & Doyle, 2004; Pyhälä et al, 2011; Johnson, Healy, Dooley, Kelly & McNicholas, 2015). In addition, there is evidence for a link between low birth weight and later ADHD (Halmøy, Klungsøyr, Skjærven, & Haavik, 2012).

Maternal pregestational diabetes can amplify the risk of various perinatal complications such as macrosomia, respiratory distress syndrome, hypoglycemia, hypocalcemia, and hyperbilirubinemia (Ogata, 2010). In their review of 14 articles, Adane, Mishra, and Tooth (2016) also found support for negative association between maternal diabetes and the child's cognitive development, although not all of the studies supported this hypothesis and most did not fully account for possible confounders such as maternal BMI, socioeconomic status, and drug use. The mechanism by which maternal diabetes may be related to the child's cognitive development is not clear. Some suggested pathways include in-utero exposure to high or fluctuating glucose levels affecting brain development, a pleiotropic gene effect between IQ and risk of diabetes, and the shared environment between the mother and child (Fraser & Lawlor, 2014).

The term perinatal asphyxia refers to an instance where the blood oxygen level of a fetus or neonate is reduced. In such a case, blood flow concentrates in vital organs, and the increase in anaerobic metabolism can result in metabolic acidosis (Timonen & Erkkola, 2004). Compared to the control group, subjects with moderate perinatal asphyxia exhibited poorer performance in delayed recall (both visual and verbal), as well as response inhibition (STROOP color-word interference) tasks (Mañeru, Junqué, Botet, Tallada & Guardia, 2001). Continued oxygen deprivation damages the brain, and perinatal asphyxia is a major cause of neonatal encephalopathy. Children who have suffered mild neonatal encephalopathy do not seem to differ markedly from their healthy peers, those with moderate encephalopathy have been reported to exhibit poorer performance in cognitive tasks pertaining to memory (Gonzales & Miller, 2006), executive functions, and attention (Marlow, Rose, Rands & Draper, 2005). Neonatal encephalopathy has also been linked to increased hyperactivity (Gonzales & Miller, 2006; Marlow, Rose, Rands & Draper, 2005). Further, Lindström, Lagerroos, Gillberg, and Fernell (2006) found statistically significant differences between teenagers with moderate neonatal encephalopathy and their healthy siblings on the Conners 10-item scale and the Inattention subscale of the ADHD rating scale IV. Finally, Moster and Markestad (2002) reported an association between symptoms of neonatal encephalopathy and ADHD related diagnoses in children, irrespective of their Apgar score.

Hyperbilirubinemia, the excess of bilirubin in blood, can be caused by a variety of reasons including liver dysfunction and pronounced destruction of red blood cells. High blood bilirubin can present as jaundice, i.e. yellowness of the skin and eyes. Prolonged excessive bilirubin can cause neurotoxic damage to the brain, and in more severe cases, cause a brain dysfunction syndrome called kernicterus. In the cohort sample used in the current study, the risk of having at least one neurobehavioral disability was five times higher for those with hyperbilirubinemia when compared to the control group (Hokkanen, Launes & Michelsson, 2014). At 30 years old, the subjects with perinatal hyperbilirubinemia, both with and in the absence of neurobehavioral disabilities, reported more childhood inattention and hyperactive-impulsive symptoms compared to the controls. The reports on current inattention and hyperactive-impulsive symptoms did not differ significantly between the groups. Jangaard, Fell, Dodds, and Allen (2008) found a tentative connection to ADHD in the severe hyperbilirubinemia group. In contrast, Vandborg et al (2015) found no connection between impaired executive functions and hyperbilirubinemia in the absence of moderate to advanced bilirubin encephalopathy.

1.2.3 Prevalence and persistence

According to meta-analyses, the worldwide prevalence of ADHD is 3.4 – 7.2 % in children aged 6 to 18 years (Polanczyk, Salum, Sugaya, Caye, & Rohde, 2015; Thomas, Sanders, Doust, Beller, & Glasziou, 2015) and 2.5 – 3.4 % in adults (Simon, Czobor, Balint, Meszaros, & Bitter, 2009; Fayyad et al, 2007). It is more common in men than women, although the proportion of women increases as the age of the examined group rises (Simon et al, 2009). The prevalence of ADHD shows a descending trend towards adulthood, with incidence decreasing by half every year after the age of 9 (van Lieshout, Luman, Buitelaar, Rommelse, & Oosterlaan, 2013).

The persistence of ADHD into adulthood ranges between 4 – 55 % depending on the study (Mannuzza, Klein, Bessler, Malloy, & LaPadula, 1998; Lara et al., 2009; Kessler et al., 2010; Ebejer et al., 2012). This wide variance could be explained by differences between studies in how remission is specified; the rate seems to be 60 – 65 % on a syndromatic level, but a mere 10 – 15 % for full symptomatic remission (Faraone, Biederman, & Mick, 2006; Biederman et al., 2011). This suggests that a number of adults will continue to have some symptoms associated with ADHD despite no longer meeting the full criteria for the disorder. Childhood inattention symptoms are more likely to persist into adulthood compared to the hyperactivity/impulsive symptoms (Kessler et al, 2010). In addition, the level of impairment caused by the symptoms, maternal psychiatric disorder, comorbid bipolar or anxiety disorder (Biederman et al, 2011), as well as treatment for ADHD in childhood (van Lieshout et al, 2013) seem to predict the persistence of ADHD.

There does not appear to be a direct connection between the alleviation of ADHD symptoms and the improvement of functioning. Both adults with ADHD and adult ADHD remitters performed more poorly than controls, and at a similar level to each other, when measuring high level cognitive skills, such as cognitive regulation, and low-level skills, such as information processing speed (van Lieshout et al, 2013). Thus, it is important to make a distinction between the diagnostic and symptom-based viewpoint in defining ADHD. The diagnostic definition of ADHD requires that set criteria, based on a diagnostic manual, be met for the condition to be present and registered. However, remission on a diagnostic level does not necessarily coincide with the alleviation of specific symptoms or difficulties in everyday tasks. As such, in the context of this study, it is reasonable to examine the effects of ADHD on the level of specific symptoms rather than focusing on the fulfillment of the whole diagnostic criteria.

1.2.4 Executive functions in ADHD

Traditionally, ADHD has been understood through the symptoms of inattention and hyperactivity-impulsiveness. In today's literature, however, there is marked interest in exploring the disorder from the viewpoint of executive functioning as well. In his landmark theory of EF in ADHD, Barkley (1997) suggests disinhibition as the central deficiency in ADHD. Barkley posits that four other executive functions – working memory, self-regulation of affect, motivation and arousal, internalized speech, and reconstitution – rely on effective inhibition and are thus secondarily impaired in ADHD. Impairment in working memory would manifest as difficulties in accessing and manipulating internally represented information as well as being more susceptible to external stimuli. Barkley emphasizes the role of working memory in the development of hindsight and foresight, with impaired inhibition thus contributing to a sort of temporal myopia. Impairment in self-regulation could in turn cause difficulty of persisting in goal-directed behavior and regulating emotional responses. This could make the person more reliant on external motivators to guide his or her behavior. Impairment in internalization of speech would affect the person's ability to inspect and guide his or her behavior through internalized speech – Barkley further suggests a connection to delayed moral reasoning. Finally, impaired reconstitution, that is, the ability to construct novel and complicated behavioral sequences could manifest as difficulties in complex language fluency and creative behavioral strategies. In sum, Barkley (1997) suggests that disinhibition as the core difficulty in ADHD can lead to a behavioral pattern that is more reliant on immediate surroundings and external motivators, rather than internalized guidance and manipulation of knowledge. The deficients in inhibition would also make people with ADHD more susceptible to distractors when compared to their typically developed peers.

Sonuga-Barke (2003) combines the executive dysfunction basis of ADHD into a motivational theory in his dual pathway model of ADHD. He argues that the behavioral expression of ADHD is rooted in both the executive circuit associated with dorsal fronto-striatal circles and meso-cortical dopaminergic connections and the fronto-ventral striatal reward circuit of the brain, which contribute to deficits in inhibition and executive functioning, and delay aversion respectively. This theory views ADHD as a disorder of executive functioning and motivation, accounting for the heterogeneity of cognitive and executive symptoms seen in people with ADHD (Sonuga-Barke, Bitsakou, Thompson, 2010). In the later expansion to the model, a third pathway of temporal processing was suggested; Sonuga-Barke, Bitsakou, Thompson (2010) found that disinhibition, delay aversion, and temporal processing deficits presented as discrete neuropsychological components in people with ADHD, with a notable portion only suffering from one of them.

People with ADHD show impaired function in a variety of EF measures. In children, those with ADHD perform worse compared to peers in tasks pertaining to response inhibition, planning, and visual and verbal working memory (Willcutt, Doyle, Nigg, Faraone & Pennington 2005; Holmes et al, 2010), as well as set shifting and sorting (Holmes et al, 2010). More specifically, children with ADHD were significantly more prone to making errors in the Trail Making Test and the Color-Word interference test, and showed less sophisticated problem solving and conceptual thinking abilities on the Card Sort test (Holmes et al, 2010).

In adults, those with ADHD have similarly been found to exhibit difficulties in measures of EF. Adults with ADHD performed worse than their healthy peers in verbal fluency, set shifting, and inhibition (Boonstra, Oosterlaan, Sergeant & Buitelaar, 2005) as well as sustained attention and working memory (Mostert et al, 2015). According to Mostert et al (2015), however, the effect sizes of the findings were small to moderate, with 11 % of the ADHD group not exhibiting EF deficits. This ties to the heterogeneity of ADHD cognitive symptom expression discussed by Sonuga-Barke and colleagues (2010). In terms of singular EF measures, high-IQ adults with ADHD performed more poorly compared to non-ADHD peers in the WCST, Stroop Color and Word Test, the ROCF, California Verbal Learning Test (CVLT) and an auditory continuous performance test (CPT) (Antshel et al, 2010). In a meta-analysis of working memory, adults with ADHD showed moderate deficits in both visual and verbal working memory tasks compared to peers (Alderson, Kasper, Hudec & Patros, 2013). In addition, the visual tasks that required more mental manipulation showed pronounced differences between the groups, alluding to the role of executive functions as a component of working memory.

1.3 The Rey–Osterrieth complex figure

The Rey-Osterrieth Complex Figure is a neuropsychological test developed by André Rey (1941) for the assessment of visuospatial abilities and visual memory in patients with traumatic brain injuries (Shin et al., 2006). In 1944, the procedure was standardized by Paul-Alexandre Osterrieth who also provided an initial normative sample for the test. The ROCF is a complicated cognitive task suitable for evaluating several neuropsychological functions, such as attention, visuospatial perception, nonverbal memory, and organization (Shin et al, 2006). It is used for research and clinical assessment of both children and adults. The objective of the ROCF is to draw an intricate geometric figure by following the provided model picture (the Copy condition) and again from memory after a retention period, usually 30 – 45 minutes (the Delayed condition). Additionally, depending on the administration method used, the ROCF may be drawn from memory at once after the copying (the Immediate condition). In the Copy condition, the researcher may fill a flow chart or replace the participant's pen with a different color at certain intervals to observe the drawing order.

1.3.1 Scoring the ROCF

Several quantitative and qualitative scoring systems have been developed for assessing the ROCF. One of the most widely used quantitative systems is the 36-point system by Osterrieth, which combines the presence and accuracy of 18 features of the figure into a single sum score (Stern et al, 1994). Another scoring system, the Developmental Scoring System (DSS) was developed to evaluate the evolving ROCF performance of children; the qualitative scores it considers are organization, style, accuracy, and errors (Shin et al, 2006). One shortcoming of the 36-point system, and other strictly quantitative scoring methods, is that they leave out potentially important qualitative information, i.e. the organizational factors such as the order a person draws the figure in (Canham, Smith & Tyrrel, 2000).

The Boston Qualitative Scoring System was developed by Stern et al (1994) to be a comprehensive qualitative scoring system for adults, although it has been used for children as well. The BQSS divides the ROCF into three hierarchical categories: the large main elements of the figure (i.e. the configural elements), the shapes and line groups around the main elements (the clusters), and the simple one-line elements (the details) (Stern et al, 1994). Each element is evaluated by its presence, accuracy, and placement, in addition to which the BQSS has a host of qualitative such as the neatness, perseveration, and confabulation. Several sum scores can then be calculated from the raw data, and these can be used to further assess the performance of the participant in all three drawing conditions as well as to evaluate memory retention from one condition to another. The evaluation criteria of the BQSS were developed based on the literature on visuoconstructional functioning and visuospatial learning (Cahn et al, 1996), as well as a review of patients with different neurobehavioral disorders (Stern et al, 1994).

1.3.2 The ROCF as a measure of executive functions

The test stages of the ROCF yield different types of information about the participant's neurocognitive functions. The task has been used to assess visuospatial processing and nonverbal memory in various patient groups, such as those with traumatic brain injuries (Ashton, Donders & Hoffman, 2005), Parkinson's disease (Scarpina, Ambriel, Albani, Pradotto, & Mauro, 2016), or major depressive disorder (Hammar & Schmid, 2013). In addition, the ROCF has been used to evaluate executive functions, especially those related to planning and organization (e.g. Somerville, Tremont & Stern, 2000; Watanabe et al, 2005). In clinical work, this is often achieved through visual inspection of the reproduction.

In his introduction to the ROCF, Rey expresses that an individual's performance in the task is linked to his or her ability to analyze the figure in a combinatory and hierarchical fashion, stating that "the normal adult sees a "whole" composed of certain units, which themselves are made up of simpler, more basic, units. In the process of making the copy, this analytic tendency is manifested quite clearly" (English translation by Corwin & Bylsma, 1993). This position is similar to the idea of a global precedence effect, that is, a healthy person's tendency to focus on general shapes first and then move towards the details of the visual field (Navon, 1977). Following this assumption, a piecemeal approach to the ROCF could indicate an underlying difficulty in organizing the figure into meaningful units. Poor organizational strategies can manifest as haphazard placement of the figure or the elements, incoherent order of drawing, lack of cohesion in the figure, and noticeable perseveration (Somerville, Tremont, & Stern, 2000).

Some evidence suggests that healthy individuals may indeed adhere to a hierarchical approach in drawing the ROCF. The tendency to begin drawing from the large frame, followed by the inner and finally outer groups was observed in a small sample of postgraduate students (Obaidellah & Cheng, 2015). The participants made longer pauses between patterns than during them and most often completed a pattern before moving on to the next one, further supporting the idea of unit combining, or chunking. It is also worth noting that ROCF Copy performance and memory encoding has been found to correlate with the tendency to draw the elements continuously rather than in parts (Shorr, Delis & Massman, 1992), as well as the DDS scores for planning and organization (Beebe, Ris, Brown & Cietrich, 2004). However, it seems that healthy people use an array of strategies with the ROCF as well, not all of which comply with the idea of the global precedence effect. These strategies can change depending on the culture, mood, and various psychological variables such as the participant's personality (Wilson & Batchelor, 2015). In a study by Wilson and Batchelor (2015), just 53 % of the healthy participants completed the main rectangle of the figure first and a mere 18 % drew the bisectors with two lines immediately after it. This variation in the order of drawing was unrelated to the accuracy and placement scores in the Copy condition. These findings should be taken into consideration when interpreting the planning and organization scores of the ROCF.

The practitioner's manual to the BQSS by Stern et al (1999) emphasizes five sub-scales that are designed to measure executive functions: planning, fragmentation, neatness, perseveration, and the organization summary score. Each of these sub-scales have been found to correlate significantly with some measures of executive functioning in adults, such as the Wisconsin Card Sorting Test perseveration, and the total words in the Controlled Oral Word Association Test, with the organization sub-scale also being suitable for rating the participants in terms of the severity of their executive dysfunction (Somerville, Tremont, & Stern, 2000). In a similar vein, BQSS summary scores for ROCF correlated with performance in the WCST, WISC-III Mazes, Digit Span, and Block Design in children aged 5 to 14, with the notable exception of the organization sub-scale (Watanabe et al, 2005). Watanabe et al. hypothesized that this inconsistency could be due to difference or immaturity in the planning and organization processes of children compared to adults. There are also some studies of children where significant correlations between EF measures and ROCF performance were not found (Weber, Riccio & Cohen, 2013; Beebe, Ris, Brown & Cietrich, 2004), although these studies employed scoring methods other than the BQSS.

Children with ADHD get significantly lower scores on the BQSS configural accuracy, cluster accuracy, detail presence, vertical and horizontal expansion, and neatness compared to the controls, while there is no such difference in fragmentation and planning (Cahn et al, 1996). Adults with ADHD perform more poorly in terms of configural accuracy, neatness, perseveration, and planning (Schreiber et al, 1999). While configural accuracy and neatness seem to be relevant measures of dysfunction regardless of age, the planning score does not discriminate between the ADHD and control groups until adulthood. This could be explained by a floor effect when examining children; their planning strategies are still immature in general and thus a measurable difference between groups does not emerge until adulthood when the human brain has fully matured (Cahn et al, 1996). It is also interesting to note that with age, the expansion sub-scale seems to lose its effectiveness in discriminating between ADHD and control groups. This could point to childhood problems in motor inhibition and anticipating the next move (Cahn et al, 1996) that are alleviated as the person approaches adulthood (Schreiber et al, 1999).

1.4 The purpose of this study

Several studies have found that individuals with childhood ADHD symptoms continue to exhibit dysfunction of executive functions as adults. There is also prior evidence that these difficulties can be demonstrated with a qualitative assessment of the ROCF reproductions. Thus, the purpose of this study is to examine the following questions:

1. Do the participants with childhood ADHD symptoms receive lower BQSS executive scores in the three ROCF conditions (Copy, Immediate, and Delayed) in adulthood compared to those without such symptoms in a perinatal risk cohort, and when compared to controls?

2. Are lower BQSS executive scores related to more self-reported everyday problems with executive functioning in BRIEF-A?

2. Method

2.1 Participants

2.1.1 The cohort for the PLASTICITY longitudinal study

This study was a part of a larger longitudinal follow-up cohort study, PLASTICITY, for which each child born in the Institute of Midwifery, Helsinki between the years 1971 and 1974 (n=22358) were screened for perinatal risk factors (Michelsson, Ylinen, Saarnivaara, & Donner, 1978). The original study sample consisted of 1196 children (5.35 % of live births) who were exposed to one or more perinatal risk factors. The qualification criteria for the study included a birth weight of less than 2000 grams, an Apgar score of less than 6 at 5 or 15 minutes, hyperbilirubinemia, breathing difficulties necessitating CPAP, neurological symptoms, hypoglycemia, maternal diabetes, and severe infections such as meningitis or sepsis. The control sample was formed from children who were born in the same hospital during the study period (Hokkanen, Launes, & Michelsson, 2013). Fifty-eight of them were followed from the age of five, and 111 since they were nine years old. A group of twin siblings of the risk cohort were followed up on as well.

A total of 155 children from the study sample died before the age of five, and further 27 were excluded from the study due to a severe developmental disability (Hokkanen, Launes, & Michelsson, 2013). The rest of the participants were invited to follow-up examinations at ages five and nine, after which they were contacted again at ages 16 and 30.

Around the age of 40, the participants were once again approached and asked whether they would like to take part in the next examination and give permission to use their information for the purposes of the study. The participants who gave their consent were asked to fill out a questionnaire and then invited to a comprehensive examination which included an MRI scan, a neurological assessment, and a neuropsychological assessment. The ROCF reproductions and the BRIEF-A questionnaires examined in the present study were completed as a part of the neuropsychological assessment.

The project had been approved by the Ethical Review Board of the Helsinki and Uusimaa hospital district (147/13/03/00/2013).

2.1.2 The participants of the present study

The sample for the current study was formed from participants for whom both a completed ROCF, and sufficient information on childhood ADHD symptoms were available (n=479). These participants were then screened for additional exclusion criteria: 10 were excluded due to schizophrenia, 5 due to brain injury, 2 due to severe disability, and 2 for other reasons. Additionally, twin siblings (n=15) were excluded from the control group. The final sample comprised of 445 participants. Within the sample, 376 participants had an underlying perinatal risk factor, while 69 were part of the control group. The primary perinatal risk factors of the participants are listed on table 1. Of the participants, 101 (22.7 %) were exposed to two or more perinatal risk factors.

2.1.3 The ADHD symptom groups

For the purposes of the present study, the participants with perinatal risk factors were divided into groups based on their childhood ADHD symptoms. However, the diagnostic information available from the childhood of the participants was not directly comparable with the modern criteria of ADHD as during the 1970's, when the longitudinal cohort study began, such a diagnosis was not yet in use. To compare and match the childhood symptoms to the ADHD criteria in the DSM-5, the clinical assessments by a neurologist, a speech therapist, and a psychologist, as well as the informant reports from parents, day care teachers, and schoolteachers, from when the participants were 5 and 9 years old, were analyzed. According to this information, the participants were retrospectively assigned to one of three ADHD symptom groups: no ADHD symptoms (NonADHD), a medium level of ADHD symptoms (MeADHD), and a high level of ADHD symptoms (HiADHD) (Schiavone et al. 2019, see Appendix 1). The controls had no perinatal risks, and no known ADHD symptoms.

Table 1. *The primary perinatal risk of each participant in the risk sample, arranged by the ADHD symptom group.*

Perinatal risk	**HiADHD % (n)**	**MeADHD % (n)**	**NonADHD % (n)**	**total % (n)**
Apgar points <6 (at 5 or 15 min)	17.6 (6)	20.8 (16)	24.5 (65)	23.2 (87)
Birth weight <2000g	32.4 (11)	25.9 (20)	20.4 (54)	22.7 (85)
Hyperbilirubinemia	17.6 (6)	32.5 (25)	33.2 (88)	31.8 (119)
Maternal diabetes	11.8 (4)	10.4 (8)	6.4 (17)	7.8 (29)
Hypoglycemia	11.8 (4)	5.2 (4)	3.4 (9)	4.6 (17)
Neurological symptoms	8.8 (3)	2.6 (2)	7.2 (19)	6.4 (24)
Other	0.0 (0)	2.6 (2)	4.9 (13)	3.5 (13)
Total	100.0 (34)	100.0 (77)	100.0 (265)	100.0 (376)

2.2 Study methods

2.2.1 The background variables

The background variables, as well their differences from group to group, are described on table 2. The variable for family socioeconomic status (SES) was formed by comparing the work status of the father when the participants were 0, 5, 9, and 16 years old and choosing the highest one. If information for the father was unavailable, information from the mother was used instead. Information was obtained from the parents with questionnaires over the course of the follow-up. For the present study, two of the lowest levels were combined, resulting in three levels of family SES. This was done due to the lowest level only having one observation within the sample. Education was evaluated by forming three groups – basic, secondary, or tertiary level – based on the participant's highest level of education reported at 40. The basic level included the nine-year-long Finnish comprehensive school. The secondary level consisted of completed or partial studies in an upper secondary school or a vocational school, as well as a completed matriculation examination. Finally, the tertiary level included completed or partial studies in a university or a university of applied sciences, as well as the bachelor's, master's, licentiate, and doctoral degrees. The full-scale intelligence quotient (FSIQ) from WAIS-IV, assessed at approximately 40 years of age, was added as a general indicator of cognitive performance.

Table 2. *A summary of background information and the inter-group differences in the study sample.*

	HiADHD	**MeADHD**	**NonADHD**	**control**	**F/χ^2**	**p**
n (%)	34 (7.6)	77 (17.3)	265 (59.6)	69 (15.5)	-	-
Age in years, mean (sd)	41.9 (1.18)	42.2 (1.21)	42.2 (1.31)	41.5 (1.29)	5.838	<.001
Gender, the % of women	35.3	41.6	54.2	56.5	8.127	.043
Family SES, % (n)					6.398	.380
Low level	32.4 (11)	28.6 (22)	23.8 (63)	14.5 (10)		
Mid level	35.3 (12)	31.2 (24)	34.3 (91)	42.0 (29)		
High level	32.4 (11)	40.3 (31)	41.9 (111)	43.5 (30)		
Level of education*, % (n)					45.268	<.001
Basic level	35.3 (12)	11.8 (9)	5.3 (14)	1.4 (1)		
Secondary level	38.2 (13)	55.3 (42)	55.7 (147)	47.8 (33)		
Tertiary level	26.5 (9)	32.9 (25)	39.0 (103)	50.7 (35)		
WAIS-IV FSIQ, mean (sd)	94.6 (19.0)	101.5 (19.5)	108.5(17.0)	114.2(15.0)	13.075	.001

SES = socioeconomic status, FSIQ = full-scale intelligence quotient, *missing n=2

2.2.2 The BQSS sub-scales for measuring executive function

In the current study, the participants completed all three conditions of the ROCF. Each of the reproductions were drawn on A4-sized, horizontally oriented papers in pencil. First, the participants were asked to copy a complex geometric figure to a blank paper according to a visible reference picture (Copy). Next, the reference was taken away and immediately after, the participants were instructed to draw the same picture again on a new blank paper, now from memory (Immediate). Finally, after a retention period of approximately 30 minutes, the participants were asked once more to draw the same picture on a blank paper, again from memory (Delayed). Each reproduction was timed with a stopwatch but there was no time limit for completing the reproductions. Rather, the participants were instructed to draw the figure as carefully and accurately as possible. In the Copy condition, the examiner documented the participants' drawing order onto a separate copy of the reference picture: each line was numbered in ascending order, beginning from number 1. Any additional or repeated lines were also marked on this reference sheet.

The BQSS executive sub-scales were selected for analyzing based on the ones implicated in the BQSS manual (Stern et al., 1999), excluding Reduction, defined as the extent to which the proportions of the reproduction are smaller than those of the model picture, which exhibited a very noticeable ceiling effect in this sample. Table 3 features a concise summary of each of the BQSS sub-scales used (for detailed descriptions and the scoring criteria, see Stern et al., 1999). The executive BQSS sub-scales derived from each of the three conditions of the ROCF were used in this study. Each variable was scored on a scale of 0 – 4 points, where 4 signified the best performance and 0 the weakest.

Two bachelors of psychology graded the Rey-Osterrieth reproductions separately using the BQSS. Of the final sample, 65 participants were given scores by both graders, and the remaining 380 by either grader 1 or 2. From the reproductions that were scored twice, intraclass correlation coefficients (ICC) were calculated for each of the BQSS executive sub-scales to examine the level of agreement between the two scorers (table 4). Referencing on the ICC interpretation guidelines proposed by Cicchetti (1994), most the coefficients for the sub-scales in all three ROCF conditions were in the 'good' or 'excellent' range ($.600 \leq r \leq 1.000$). The sub-scales with coefficients below that, Copy configural accuracy, Delayed neatness, and Copy perseveration, were all within the 'fair' range ($.400 \leq r < .600$). Outside of the ICC analysis, only one scoring per participant was included in the analyses; it was decided beforehand that the scores by grader 1 would be used for participants that had been scored by both graders.

Table 3. *Descriptions of the ROCF and BRIEF-A sub-scales examined in the present study.*

Method	***Variable name***	***Description***
ROCF	Configural accuracy	The accuracy of the six configural elements of the ROCF are compared to the model picture in terms of their similarity and relative placement.
	Planning (Copy condition)	The order of drawing, the placement of the figure on the sheet and of the elements within it, as well the integrity of the figure.
	Neatness	The neatness of the reproduction. Points are reduced for various neatness violators, such as gaps and overshoots, as well as tremulous lines.
	Fragmentation (Copy condition)	An assessment of whether the elements are drawn as complete wholes or in parts. The score is calculated by examining the six configural elements and cluster 1.
	Perseveration	An assessment of whether additional repetitions of the elements or parts of them are produced.
	Horizontal and vertical expansion	A model frame is used to determine whether the size or the proportions of the reproduction are larger than the model picture.
BRIEF	Inhibit	The ability to resist impulses and stop one's behavior.
	Shift	The ability to shift between tasks or situations flexibly.
	Emotional Control	The ability to control one's emotions according to the situation.
	Self-Monitor	The ability to examine one's behavior and its effects in various social situations.
	Initiate	The ability to begin a task or generate ideas.
	Working Memory	The ability to hold task-relevant information in mind.
	Plan/Organize	The ability to set goals and plan the steps needed to complete them. The ability to anticipate future events.
	Task Monitor	The ability to examine and assess one's own performance during and after the completion of a task.
	Organization of Materials	The ability to keep one's daily environments in order.

Table 4. *The agreement between scorers explored employing intraclass correlation coefficients.*

	ICC single measures		
	Copy	**Immediate**	**Delayed**
Configural accuracy	.512	.857	.633
Configural fragmentation	.841	-	-
Planning	.729	-	-
Neatness	.705	.677	.417
Vertical expansion	.944	.928	.948
Horizontal expansion	.961	.694	.977
Perseveration	.481	.822	.852

All coefficients p<.001

2.2.3 The BRIEF-A Clinical Scales

As a part of their neuropsychological assessment, the participants were asked to complete the self-report version of BRIEF-A. The BRIEF-A form consists of 75 statements such as “I make careless errors when completing tasks” and “I forget instructions easily” which pertain to the nine clinical scales described in table 3 (see Roth, Gioia, & Isquith, 1996 for more details). The participants were to consider their behavior during past month and answer each statement based on how often they had encountered the described issue, their options being “never”, “sometimes”, and “often”. These answers were scored as one, two, and three points respectively, with a higher total score indicating more pronounced difficulties in everyday functioning. In this study, all nine BRIEF-A clinical scales (table 3) were examined. To form the raw sum score for each clinical scale, the points from every item corresponding to a particular scale were added together. These were then to be compared to the participants’ ROCF reproduction scores.

2.3 Statistical analyses

The distribution of several BQSS executive sub-scales, particularly the vertical expansion and reduction sub-scales, was visibly left-skewed when examined from histograms and quantile-quantile plots. This was further confirmed with Shapiro-Wilk test of normality with which each of the BQSS sub-scales were found to be non-normally distributed. A series of multinomial logistic regression analyses were then performed to predict the membership in the ADHD symptom groups with the BQSS executive sub-scales. However, the scoring categories of the BQSS sub-scales had to be modified due to the pronounced skewness of the data; scores 0-

2 were combined into one category marked with ‘1’, while score 3 was recoded into a ‘2’ and 4 to a ‘3’ respectively. After these amendments, the logistic regression analyses were rerun.

The examined background variables that had been found to differ statistically significantly between the ADHD symptom and control groups were included in the analyses. Out of the background variables, age was left out as it bears no clinical significance in this study sample (the mean age of all groups is ~42 years). The three ROCF conditions–Copy, Immediate, and Delayed were examined in the following ways:

1) Each BQSS variable was examined one by one, in addition to the level of education, the WAIS-IV FSIQ, and the gender of the participant as the background variables.
2) All of the BQSS sub-scales were combined into a single regression model.
3) The three background variables were added to the combined model.

Furthermore, the association between the BQSS executive sub-scales and the BRIEF-A clinical scales was examined using Spearman’s correlation coefficients.

3. Results

3.1 The association between ROCF executive scores and childhood ADHD symptoms

The performance of the study groups as well as the control group in the three ROCF conditions, when assessed with the executive sub-scales of the BQSS, is presented in figure 1. Configural fragmentation and Planning were only assessed in the Copy condition.

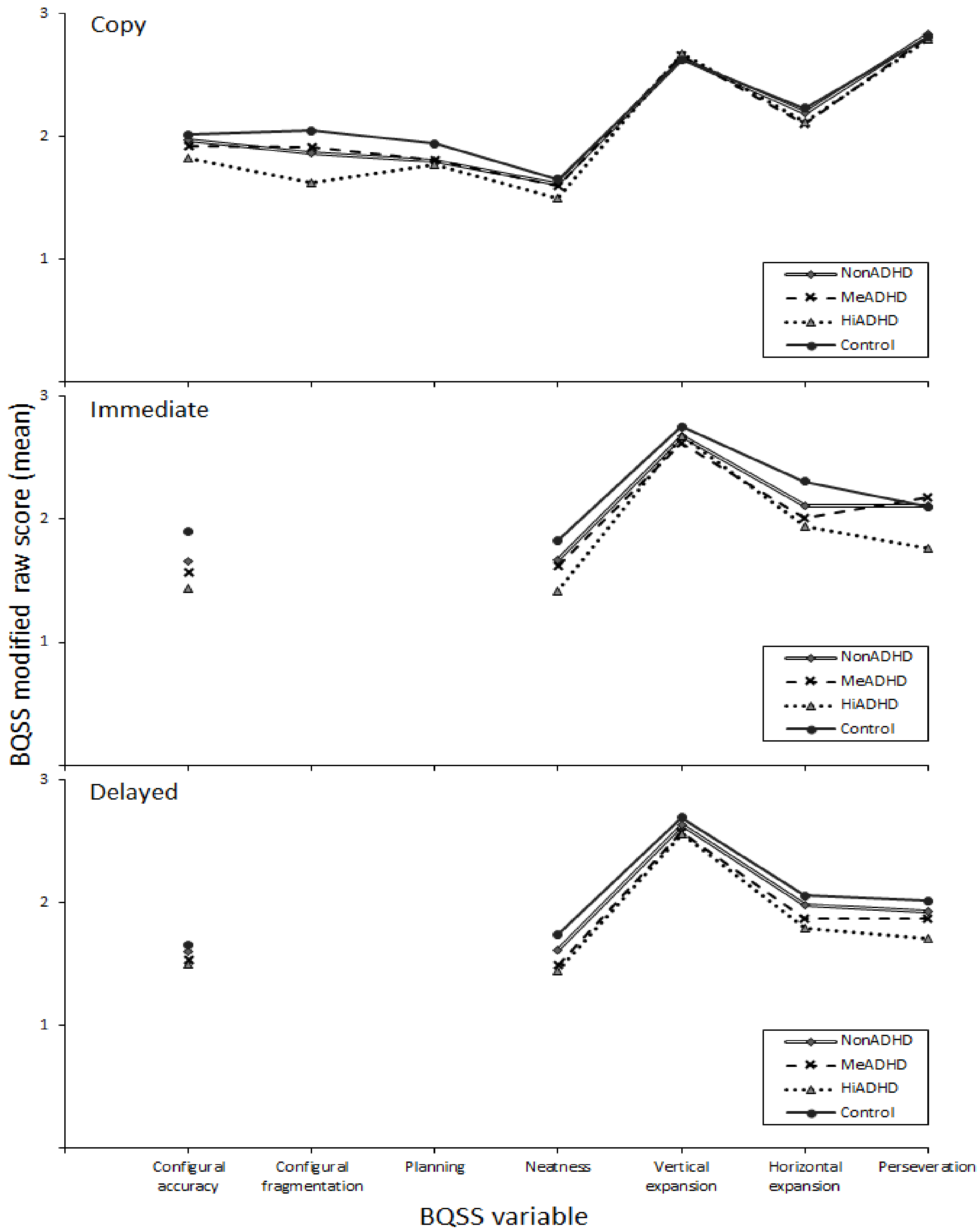

***Figure 1**. Study group means of the modified BQSS executive scores in the three ROCF conditions.*

3.1.1 The Copy condition

When the BQSS executive sub-scales were examined one by one, Configural fragmentation was a significant predictor of the ADHD symptom group membership (table 5). Examining both the logistic regression analysis and visual information (figure 1) it was found that participants in the HiADHD group scored lower in Configural fragmentation, i.e. their ROCF reproductions exhibited more fragmentation, than the other groups. The control group exhibited the least fragmentation in their reproductions. All three background variables were significant predictors of the group membership when examined separately (table 5).

Table 5. *The ROCF Copy condition BQSS sub-scales and the background variables as separate predictors of ADHD symptom group membership.*

	-2 Log Likelihood of Reduced Model	χ^2	df	p
Configural accuracy	44.596	3.501	6	.744
Configural fragmentation	55.266	14.411	6	.025*
Planning	46.182	5.232	6	.514
Neatness	40.698	6.696	6	.350
Vertical expansion	39.145	1.253	6	.974
Horizontal expansion	44.528	3.263	6	.775
Perseveration	38.262	3.698	6	.718
Level of education	71.810	33.488	6	.000***
WAIS-IV FSIQ	451.871	36.856	3	.000***
Gender	38.122	8.184	3	.042*

*p<.05, ***p<.001

Next, all seven BQSS executive sub-scales were added to a single regression model. In this scenario, Configural fragmentation was again found to be a significant predictor of ADHD group membership (table 6). Finally, the tree background variables were added to the model. They were all significant predictors of the ADHD symptom group membership (level of education χ^2=13.973 p=.030; FSIQ χ^2=27.997, p<.001; gender χ^2=14.718, p=.002), while the seven BQSS executive sub-scales were now statistically nonsignificant.

Table 6. *The ROCF Copy condition BQSS sub-scales as predictors of ADHD symptom group membership in the same regression model, without background variables.*

	-2 Log Likelihood of Reduced Model	**χ^2**	**df**	**p**
Intercept	667.223	.000	0	.
Configural accuracy	669.148	1.925	6	.926
Configural fragmentation	680.409	13.186	6	.040*
Planning	672.303	5.080	6	.534
Neatness	672.741	5.517	6	.479
Vertical expansion	669.987	2.764	6	.838
Horizontal expansion	673.774	6.551	6	.364
Perseveration	670.752	3.529	6	.740

*p<.05

3.1.2 The Immediate condition

When the BQSS executive sub-scales were analyzed one by one, Neatness and Horizontal expansion were significant predictors of the ADHD symptom group membership, with Perseveration approaching statistical significance (table 7). When examined together with a visual representation of the group mean scores (fig. 1), it was found that the participants in the HiADHD group scored the lowest on the Neatness and Horizontal expansion sub-scales. This means that their ROCF reproductions were in general less neat and exhibited more horizontal distortion than the reproductions by other groups. As in the Copy condition, the control group scored the highest out of all groups in both variables, as observed in figure 1.

Next, all BQSS executive sub-scales were added to a single regression model. This time, none of the BQSS executive sub-scales were significant predictors of ADHD symptom group membership (table 7).

Thirdly, the background variables were added to the model and among them, the FSIQ and participant gender were found to be significant predictors of ADHD symptom group membership, while out of the BQSS executive sub-scales, perseveration was a significant predictor (table 8). Those in the HiADHD group showed pronounced perseveration in their reproductions compared to the other groups.

Table 7. *The ROCF Immediate condition BQSS sub-scales as separate predictors of ADHD symptom group membership, and when added to the same regression model.*

		-2 Log Likelihood of Reduced Model	χ²	df	p
Separate	Configural accuracy	51.290	11.192	6	.083
	Neatness	50.629	16.175	6	.013*
	Vertical expansion	41.764	4.697	6	.583
	Horizontal expansion	53.568	12.666	6	.049*
	Perseveration	53.300	12.534	6	.051
Same model	Intercept	448.795	.000	0	.
	Configural accuracy	432.238	3.443	6	.751
	Neatness	439.047	10.252	6	.114
	Vertical expansion	433.554	4.760	6	.575
	Horizontal expansion	440.955	12.160	6	.058
	Perseveration	441.132	12.337	6	.055

*p<.05

Table 8. *The ROCF Immediate condition BQSS sub-scales as predictors of ADHD symptom group membership in the same regression model, including the three background variables.*

	-2 Log Likelihood of Reduced Model	χ²	df	p
Intercept	846.783	.000	0	.
Configural accuracy	848.645	1.861	6	.932
Neatness	853.398	6.615	6	.358
Vertical expansion	851.960	5.177	6	.521
Horizontal expansion	857.060	10.276	6	.113
Perseveration	861.734	14.950	6	.021*
Level of education	858.960	12.177	6	.058
WAIS-IV FSIQ	868.110	21.327	3	.000***
Gender	858.793	12.010	3	.007**

*p<.05, **p<.01, ***p<.001

3.1.3 The Delayed condition

When the BQSS executive sub-scales were examined one by one, neatness was a significant predictor of the ADHD symptom group membership (table 9), with the control group having the neatest ROCF reproductions.

Next, all BQSS executive sub-scales were added to a single regression model. This time, none of them were significant predictors of ADHD symptom group membership (table 9). Finally, the tree background variables were added to the model; the WAIS-IV FSIQ and the gender of the participant predicted ADHD group membership, while none of the BQSS executive sub-scales were significant predictors (table 10).

Table 9. *The ROCF Delayed condition BQSS sub-scales as separate predictors of ADHD symptom group membership, and when added to the same regression model.*

		-2 Log Likelihood of Reduced Model	**χ^2**	**df**	**p**
Separate	Configural accuracy	42.389	2.603	6	.857
	Neatness	45.673	13.569	6	.035*
	Vertical expansion	41.601	3.421	6	.754
	Horizontal expansion	45.463	4.567	6	.600
	Perseveration	45.916	4.872	6	.560
Same model	Intercept	442.702	.000	0	.
	Configural accuracy	444.044	1.342	6	.969
	Neatness	454.277	11.574	6	.072
	Vertical expansion	445.266	2.563	6	.861
	Horizontal expansion	446.712	4.010	6	.675
	Perseveration	447.175	4.472	6	.613

*p<.05

Table 10. *The ROCF Delayed condition BQSS sub-scales as predictors of ADHD symptom group membership in the same regression model, including the three background variables.*

	-2 Log Likelihood of Reduced Model	χ^2	df	p
Intercept	880.106	.000	0	.
Configural accuracy	883.132	3.026	6	.806
Neatness	885.205	5.099	6	.531
Vertical expansion	882.962	2.856	6	.827
Horizontal expansion	883.164	3.058	6	.802
Perseveration	883.145	3.040	6	.804
Level of education	892.333	12.227	6	.057
WAIS-IV FSIQ	904.458	24.353	3	.000***
Gender	892.458	12.353	3	.006**

**p<.01, ***p<.001

3.2 The association between the BQSS executive scores and the BRIEF-A Clinical Scales

The correlations between the BQSS executive scores and the BRIEF-A clinical scales were mostly statistically nonsignificant, barring a few exceptions which are summarized in table 11 (for the full correlation matrices, see Appendix 2). Even the statistically significant correlations were fairly modest ($r < |.150|$).

Table 11. *The statistically significant correlations (Spearman's rho) between the BQSS executive sub-scales for the ROCF and the BRIEF-A clinical scales.*

BQSS executive variable	BRIEF-A clinical scale	Correlation coefficient	p (2-tailed)
Copy configural fragmentation	Inhibit	-.117*	.013
	Self-monitor	-.126**	.008
Copy perseveration	Inhibit	-.116*	.014
	Emotional control	-.111*	.019
	Working memory	-.140**	.003
Immediate configural accuracy	Inhibit	-.101*	.033
	Working memory	-.103*	.030
	Plan	-.097*	.040
Immediate neatness	Inhibit	-.118*	.013
	Self-monitor	-.128**	.007
Delayed configural accuracy	Inhibit	-.102*	.032
Delayed perseveration	Working memory	-.106*	.026

*p<.05, **p<.01

4. Discussion

In this study, the ROCF reproductions of four participant groups were examined: three of them were comprised of people who had experienced at least one perinatal risk factor while the fourth, the control group, had no recorded history of perinatal risks or childhood ADHD. The three risk factor groups were assigned according to the retrospectively determined childhood ADHD symptoms; those with no childhood symptoms (NonADHD), those with some symptoms (MeADHD), and those with many childhood symptoms fitting the modern description of ADHD (HiADHD). It was found that the ROCF reproductions did indeed vary between the groups, and some statistically significant connections between the qualitative executive scores on the ROCF and childhood ADHD symptoms were observed. The predictive power of the ROCF scores was, however, often overpowered by the background variables, especially the WAIS-IV FSIQ and participant gender.

4.1 The association between ROCF reproductions and ADHD symptom group

In the Copy condition of the ROCF, higher amount of fragmentation, i.e. drawing the elements in parts rather than completing each of them before moving to the next, predicted ADHD symptom group membership. Upon visual inspection of the group means, those belonging to the HiADHD group seem to exhibit the most fragmentation in their reproductions and the control group the least. When the background variables for level of education, general intelligence, and gender were taken into account, the amount of fragmentation was no longer a significant predictor. In the Immediate condition, a less neat reproduction, more horizontal expansion, and more perseveration predicted ADHD symptom group membership. Perseveration remained a significant predictor after the effects or background variables were accounted for. The HiADHD group differentiated noticeably from the others with more perseveration errors. In the Delayed condition, a less neat reproduction predicted ADHD group membership but neatness became a statistically non-significant predictor once the background variables were accounted for.

The findings in this study are mostly in line with former literature on the ROCF and the BQSS. One of the core assumptions of Rey was that a typical healthy person would use a hierarchical approach beginning from the largest elements when drawing the ROCF (Corwin & Bylsma, 1993), and later literature offers some evidence that a piecemeal style in copying the figure could indicate an underlying problem in executive functions (e.g. Shin et al, 2006). Indeed, in this study on a birth risk cohort, a more fragmented approach with less elements completed uninterrupted was associated with childhood ADHD symptoms, while those without a history of perinatal risk factors or childhood ADHD symptoms tended to exhibit the least fragmentation in their reproductions. Further, it has been shown that adults with ADHD produce the

ROCF with less configural accuracy and weaker planning, and have a less neat style with more perseveration errors than their healthy peers (Schreiber, 1999). These findings received partial support in the current study: the participants with high childhood ADHD symptoms made more perseveration errors and their drawing style was less neat particularly when compared to the control group in the recall condition of the ROCF. In this study, configural accuracy or planning did not differentiate between the ADHD symptom groups. However, it is important to notice that the participants were chosen based on their childhood symptoms while the earlier study examined adults who fulfilled the diagnostic criteria at the time of the study. Their difficulties in executive functions could be more apparent in a controlled study environment, owing to their possibly more pronounced symptoms, compared to the participants of this study. The relatively noticeable disagreement between scorers on the configural accuracy scale in this study could also make it less accurate than the other inspected sub-scales – some ambiguous elements could be classified as misplaced or inaccurate configural elements, but also, for example, as repeated or incomplete clusters. Nevertheless, the current study implies that some deficits in organized task completion and meticulousness persist into adulthood even in the absence of a full diagnosis of ADHD. It is known that adults with history of ADHD can continue to exhibit difficulties in executive functions even though they do not fulfil the diagnostic criteria for the full disorder (Faraone, Biederman, & Mick, 2006; Biederman, Petty, Clarke, Lomedico, & Faraone, 2011) which is in line with this conclusion.

The background variables selected for examination in this study, gender, level of education, and the FSIQ, differentiated between the symptom groups rather consistently across the ROCF conditions, often masking the predictive qualities of the BQSS executive sub-scales when examined at the same time. It could be that the aspects of EF relevant to successful completion of the ROCF have also affected the participants' education history and performance in other tests of cognitive processes, in this case the WAIS-IV. It is not unreasonable to suggest issues in similar executive processes relevant to the BQSS sub-scales, such as disorganized behavioral strategies and tendency to perseverate or get distracted, could hinder educational success and affect a variety of cognitive processes outside those considered EF. All in all, ADHD symptoms, both the traditional inattention and hyperactive/impulsive and those related to EF, can have a multifaceted impact on a person's life path and cognitive functioning, which the findings here on education, general intelligence, and specific EF processes hint towards.

4.2 The association between ROCF reproductions and BRIEF-A reports

The general finding was that the association between the ROCF executive scores and the reports on BRIEF-A was modest, with most of the correlations being non-significant and none exceeding $r=|.150|$. Out of the BRIEF-A scales, Inhibit, Self-monitor, Emotional control, Working memory, and Plan exhibited statistically significant correlations with some of the ROCF executive scores, with Inhibit having the largest amount of correlations. Reported difficulties in inhibition were connected to more fragmentation and more perseveration errors in the Copy condition, and to a less neat reproduction, as well as reduced configural accuracy in ROCF recall conditions.

The often meager correlations between EF self-ratings and performance-based measures of EF have been acknowledged when examining a variety of study samples (Toplak, West, & Stanovich, 2013), and the findings of the current study are in line with that notion. In this study, the correlations were indeed rather modest but logical. For example, subjective difficulties in inhibition and monitoring one's own behavior could represent the same underlying problems that cause fragmentation in the drawing order. Formulating a logical copying strategy would likely call for reflecting upon one's performance as well as focusing on just certain parts of the figure at a time without getting distracted. Similarly, deficits in working memory and planning could easily relate to less accurate retrieval of the ROCF as the successful completion of a complicated visual task will benefit from one's ability to encode and maintain a coherent image in his or her mind.

While some logical correlations manifested, many hypothetically plausible ones did not, such as the Plan scale's association with the ROCF planning score. This could highlight the fact that different measures use the same terminology in different ways, as well as point towards the idea that EF ratings and performance tests measure different aspects of executive functioning entirely (e.g. Toplak, West & Stanovich, 2013). The ROCF was completed in a controlled setting and the neurological assessment, while likely taxing to the participant, is a carefully planned affair on the part of the examiner measured in hours. Contrast this to the demands of everyday life, where the environments can be markedly unstructured and many tasks and projects may need one's cognitive resources for days or months at a time. As such, it stands to reason that the participants' experiences in the two situations are different. It is also worth noting that self-reports are subject to what the person notices or knows about his or her behavior and abilities, and how he or she chooses to explain the difficulties and triumps. It could be that the reality of the participants' daily functioning is diffetent from their reports, perhaps closer to the pattern seen in laboratory settings, but the self-report information has been filtered according to their subjective experiences.

4.3 The strenghts and limitations of this study

The sample of the current study is well representative of the children born in Finland at the time, with a notable portion of the original cohort still accounted for at the 40-year mark. The PLASTICITY cohort has been closely monitored throughout the years which made it possible to examine the continuity of the problems of executive functions over a long period of time. However, as the cohort study project spans over multiple decades, the information gathered at different times was not effortlessly comparable. In this study, that fact affected the assessment of childhood ADHD as the modern diagnostic information was not available from that time. Nevertheless, the expansive multidisciplinary data made it possible to retrospectively assign participants into symptom groups based on how well their reported symptoms would fit the modern definition of ADHD. In this study, the differences between the symptom groups showed similar trends to those found in studies where the groups were based on modern ADHD diagnoses. In this light as well, the retrospective classification can be considered successful. Finally, in this study the skewness of the data due to the generally rather good ROCF performances made it impossible to use the BQSS executive variable scores as is, and some score categories had to be combined. This may have lessened the amount of information obtainable from the data, though it is worth noting that many of the combined classes contained only a handful of observations by themselves.

4.4 Conclusions

In this study, the participants were divided into groups based on childhood ADHD symptoms, as opposed to their current diagnosis, which sets it apart from earlier research. Despite this, some of the differences between the symptom groups in the ROCF reproductions were similar to those seen between adults with ADHD diagnosis and their healthy peers. It is worth noting that many of the associations found in this study became non-significant when gender, education, and general cognitive functioning were controlled. An exception to this was observed in perseveration, with the amount of such errors differentiating between the groups even when the background variables mentioned before were accounted for. In the current study sample, scores leaned towards the stronger end of the BQSS evaluation spectrum, which suggests the possibility that in this population, the more nuanced issues in executive functioning could not be captured in a well structured laboratory situation. Finally, the executive function deficits discovered with the ROCF reproductions of this sample showed only mild correlations with subjective reports of daily executive dysfunction. This is in line with the earlier knowledge on the connection between different types of EF measures.

The current study has added to the still rather sparse literature of the BQSS for ROCF as a measure of executive functions. More research is needed to expand the knowledge on exactly which aspects of executive functioning the qualitative analysis of the ROCF captures within the framework of ADHD. This study was conducted on a sample with perinatal risks as an additional variable which makes it special compared to earlier literature on the topic. However, as the number of participants on singular risk factor groups was rather small for most perinatal risks, the effects of different risks on the developmental continuity of ADHD were not examined at this time. Further research on the manifestation of executive deficits of ADHD in the presence of a birth risk is thus needed.

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Appendix 1

From Schiavone et al. 2019

Identifying ADHD symptoms

Identification of childhood ADHD symptoms was based on information gathered from clinical assessments (C) and informant reports (I) at 5 and 9 years. Maximum scores from clinical assessments and informant reports were extracted and summed to classify cases into three groups: **No ADHD (NonADHD):** C+I <2; **Subclinical ADHD (MeADHD)**: C+I=2; **Probable ADHD (HiADHD)**: C+I >2. Thus, to be classified as probable ADHD, symptoms had to be displayed in at least two different situations and were reported as severe in at least one situation.

Table A1. Information sources and scoring procedure

Type	Method	Age	Scoring	Stratification
C	Clinical Assessment	5	0,1,2	0-2 Highest score
C	Clinical Assessment	9	0,1,2	0-2 Highest score
I	Questionnaire for parents	5	Max 16 points	Compared to controls: 0=at/below 25th percentile; 1=above 25th percentile 2=above 10th percentile
I	Questionnaire for parents	9	Max 6 points	Compared to controls: 0=at/below 25th percentile; 1=above 25th percentile 2=above 10th percentile
I	Questionnaire for day care teacher	5	Max 10 points	Compared to controls: 0=at/below 25th percentile; 1=above 25th percentile 2=above 10th percentile
I	Questionnaire for school teacher	9	Max 22 points	Compared to controls: 0=at/below 25th percentile; 1=above 25th percentile 2=above 10th percentile

C = clinical assessment, I = informant report.

Clinical Assessment

The children underwent clinical assessments by a doctor, speech therapist and a psychologist. The assessors observed attention and hyperactivity symptoms during the appointments and scored the behaviour 0 (normal), 1 (mildly abnormal) or 2 (strongly abnormal).

Informant Reports

Table A2. Questionnaires in childhood		
Information source	Question	Answer
Parents at 5 years	Did your child have difficulty as a toddler with being overactive / impulsive?	yes =1 no=0
	Does your child move his/her arms, fingers or feet while sitting more than usual?	often=2, sometimes=1, no=0
	Does your child move about carelessly so that drinks may spill, objects may break of bruising may occur when tripping over?	often=2, sometimes=1, no=0
	Does your child talk excessively?	often=2, sometimes=1, no=0
	Does your child focus on activities such as looking at pictures, playing or small tasks of handicraft?	poorly=2, moderately=0, well=0
	Does your child not appear to hear you well?	yes=2, sometimes=1, no=0
	Does your child appear not to remember things?	often=2, sometimes=1, seldom=0
	Compared to other children of the same age, does your child lose his/her temper easily?	yes=1, like others=0, no=0
	Question	Answer
Day-care teachers at 5 years	Does the child finish his/her chores and tasks?	mostly no=2, sometimes=1, mostly yes=0
	Is the child able to concentrate?	poorly=1, like others=0, well=0
	Is the child attentive?	poorly=1, like others=0, well=0
	Is the child able to stay focused?	poorly=1, like others=0, well=0
	Does the child talk excessively?	yes=1, no=0
	Is the child a day-dreamer?	yes=1, no=0
	Does the child intrude or interfere with other children?	yes=1, no=0
	Is the child restless, motorly overactive?	significantly=2, moderately=1, no=0
	Question	Answer
Parents at 9 years	Is the child more active than normal?	yes=1, no=0
	Is the child easily distracted from e.g. schoolwork by extraneous noise?	yes=1, no=0
	Does the child often ask 'what'?	yes=1, no=0
	Does the child easily forget instructions that were given?	yes=1, no=0
	Does the child often fail to finish what he/she started?	yes=1, no=0
	Does the child have difficulty at school? Does the child take care of his/her schoolwork and assignments independently?	(open ended questions, scored= 1 if anything related to inattention, impulsivity or hyperactivity is mentioned)
	Question: adjective pairs / continuums; Is the child…	

<table>
<tr><td rowspan="7">Teacher at 9 years</td><td>adjective A</td><td>very (1)</td><td>moderately (2)</td><td>neither (3)</td><td>moderately (4)</td><td>very (5)</td><td>adjective B</td></tr>
<tr><td>focused</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>loses focus</td></tr>
<tr><td>quiet</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>restless</td></tr>
<tr><td>attentive</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>day-dreamer</td></tr>
<tr><td>careful</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>careless</td></tr>
<tr><td colspan="3">Is there anything noteworthy such as special talents, hyperactivity or crying, about the child?</td><td colspan="4">Open ended question, scored= 1 if anything related to inattention, impulsivity or hyperactivity is mentioned</td></tr>
<tr><td colspan="3">How does the child focus in class?</td><td colspan="4">Open ended question, scored= 1 if anything related to inattention, impulsivity or hyperactivity is mentioned</td></tr>
</table>

Appendix 2

The correlations (Spearman's rho) between the BQSS Copy condition sub-scales for ROCF and the BRIEF-A Clinical Scales.

		Inhibit	Shift	Emotional control	Self-monitor	Initiate	Working Memory	Plan	Task Monitor	Org of Materials
Configural accuracy	Correlation	-.078	.045	.052	-.064	-.004	-.077	-.064	-.055	.007
	p (2-tailed)	.099	.345	.273	.181	.934	.105	.179	.244	.882
Configural Fragment.	Correlation	**-.117***	-.023	-.044	**-.126****	-.057	-.068	-.068	-.040	.070
	p (2-tailed)	.013	.635	.359	.008	.229	.155	.155	.405	.138
Planning	Correlation	-.021	-.025	-.050	-.034	-.030	-.009	.031	.027	.065
	p (2-tailed)	.667	.607	.292	.475	.523	.855	.509	.570	.169
neatness	Correlation	**-.112***	.024	-.030	-.088	.036	-.083	-.038	-.027	.016
	p (2-tailed)	.018	.618	.525	.063	.445	.081	.427	.564	.741
Vertical expansion	Correlation	-.013	.032	-.025	.001	-.011	-.002	.010	-.005	-.048
	p (2-tailed)	.788	.496	.603	.984	.816	.970	.829	.920	.313
Horizontal expansion	Correlation	-.020	-.009	-.006	.012	-.026	-.066	.001	.004	-.025
	p (2-tailed)	.671	.849	.896	.794	.580	.165	.989	.934	.602
Perseveration	Correlation	**-.116***	-.047	**-.111***	-.082	-.076	**-.140****	-.060	-.079	-.042
	p (2-tailed)	.014	.323	.019	.083	.109	.003	.205	.094	.374

*p<.05, **p<.01

The correlations (Spearman's rho) between the BQSS Immediate condition sub-scales for ROCF and the BRIEF-A Clinical Scales.

		Inhibit	Shift	Emotional control	Self-monitor	Initiate	Working Memory	Plan	Task Monitor	Org of Materials
Configural accuracy	Correlation	**-.101***	-.052	-.006	-.089	-.037	**-.103***	**-.097***	-.038	.084
	p (2-tailed)	.033	.272	.895	.059	.430	.030	.040	.424	.076
Neatness	Correlation	**-.118***	-.021	-.050	**-.128****	.011	-.076	-.048	-.025	.012
	p (2-tailed)	.013	.666	.292	.007	.821	.111	.314	.601	.802
Vertical expansion	Correlation	.025	.060	.052	-.019	.013	.062	.029	.005	.002
	p (2-tailed)	.602	.205	.270	.685	.777	.195	.549	.924	.966
Horizontal expansion	Correlation	-.022	-.024	.010	-.022	-.069	-.050	-.032	-.010	-.039
	p (2-tailed)	.639	.617	.840	.637	.145	.296	.506	.831	.416
Perseveration	Correlation	-.047	-.084	-.051	-.057	-.017	-.078	-.042	-.005	-.036
	p (2-tailed)	.323	.076	.284	.228	.728	.101	.381	.919	.449

*p<.05, **p<.01

The correlations (Spearman's rho) between the BQSS Delayed condition sub-scales for ROCF and the BRIEF-A Clinical Scales.

		Inhibit	Shift	Emotional control	Self-monitor	Initiate	Working Memory	Plan	Task Monitor	Org of Materials
Configural accuracy	Correlation	**-.102***	-.034	-.004	-.060	-.027	-.075	-.079	-.064	.027
	p (2-tailed)	.032	.473	.941	.203	.567	.113	.095	.177	.563
Neatness	Correlation	-.085	-.027	-.033	-.072	-.002	-.070	-.064	-.057	.000
	p (2-tailed)	.074	.573	.484	.127	.964	.141	.181	.233	.992
Vertical expansion	Correlation	.000	.013	-.004	.002	-.063	.021	.031	-.024	-.027
	p (2-tailed)	.992	.780	.938	.967	.187	.664	.515	.619	.564
Horizontal expansion	Correlation	-.007	-.048	-.049	-.021	-.054	-.062	-.017	-.038	-.077
	p (2-tailed)	.890	.308	.299	.660	.258	.195	.715	.427	.106
Perseveration	Correlation	-.028	-.070	-.059	-.043	.001	**-.106***	-.067	-.058	.023
	p (2-tailed)	.558	.142	.213	.361	.988	.026	.160	.224	.633

*p<.05